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Two-stage optimization model used for community energy planning

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Abstract

Make community energy system plan at urban detailed plan stage can help to reduce fossil energy consumption and improve community energy system efficiency. A two-stage optimization model which can be used to optimize secondary energy production and distribution at community scale is introduced. Linear programming model was utilized to get the first stage optimization result, which result is calculated from design parameters. Goal programming was used to discuss the optimization results when constrain variables changed within a certain range. From this two-stage optimization model, the optimized community energy system structure and energy consumption targets can be acquired, which results have greatly contributes to community energy planning. This method has been validated by a community heating system planning project in North China.

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Keywords: community energy planning, goal programming, two-stage optimization model

1. Introduction

The main work of community energy planning at urban detailed planning stage is to collect and analyses basic data and build regulation index system, and then find an effective approach to achieve energy saving goals. So the main task of the community energy system planning at urban detailed planning stage is：

1) Data Collection: any information which is related to space heating, such as climate data, available energy resource and technical regulations, etc. 2) Setting community energy system energy consumption (contain fossil energy and renewable energy) target: how much fossil energy consumed is unavoidable. 3) Regulation and Suggestion: to give a simplified guide for subsequent community heating system design.

In order to complement the work listed above, Top-down and Bottom-up models are always used for

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community energy planning. In China, the top-down way is always based on LEED-ND [1] or BREEAM Communities [2] rating system to set renewable energy percent or energy saving goals of the community. But this reference process is difficult because the rating systems are not always suitable for most of Chinese projects. So without systematic and effective assessment indicators and methods to analyses community energy system during urban detailed planning stage, it’s hard for planners to set energy consumption goals and put forward effective proposals. For thorough analysis of community heating system, using bottom-up models to make a systematic analysis is necessary. Many bottom-up models and tools directed at community energy system have been reported by [3-9] .

Most of the models require a given system for developing the optimization process, which means they design the appropriate capacities and mix of a user-selected set of technologies [10]. It is a tough and dubious work for planners to select appropriate technologies and capacities at the community planning stage. For spatial scale, most of the tools discuss more about the connections between different buildings in one land parcel, but less about the relationships between different land parcels. So develop a new community energy system analysis model with the purpose of community energy planning is required. This community energy planning assistance model can help to determine energy related target and conduct energy municipal construction planning.

2. Community energy system

2.1 Secondary energy markets

On urban community scale, secondary energy mainly including hot water, electricity, gas/oil fuel, space heating/cooling which can be directly used during city life. Suppose each kind of secondary energy as one kinds of merchandise and the secondary energy transferred from one site to another site as the merchandise business from one person to another one. One community contains a lot of energy commodity consumption and production sites. The energy transferred between different sites constitutes secondary energy markets (primary energy transfer is out of considered).

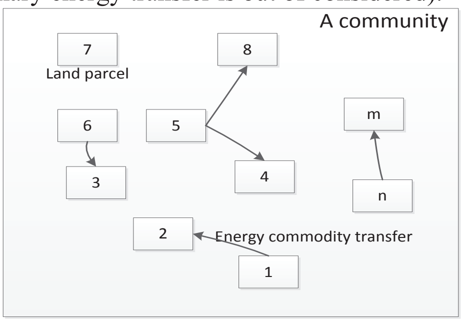

Fig. 1. The schematic of energy commodity transport between different sites

Generally, there are so many energy technologies and facilities can be used for producing energy commodities, select technologies then make more rational connections between energy production and energy consumption sites should select evaluation criteria firstly. Suppose every land parcel as a single entity and have capable produce and consume energy commodity. Every land parcel can select produce its energy demand itself or import it from others’ land parcel, which is similar like a peasant household can select produce food himself or purchase food from other household. Food prices determine the peasant household makes which decision: purchase food from A or B or others, or produce the food itself. In community energy system, we suppose all the secondary energy is “priced” (including the energy used itself) based on its production technologies and anyone choose the “available cheapest thermal energy” to satisfy its energy demand [11]. The optimization network structure of community energy transfers system can be like Fig1.

2.2 Cost model

Here the cost not only means the monetary cost but also fossil energy consumption cost, environmental pollution cost or others expend. The energy commodity expend contain production cost and energy transfer spend. In order to calculate energy transfer expend, every land parcels’ geometric coordinate is necessary. These coordinates can be leading-out form Geographic Information System (GIS), based on the geometric coordinate the distance between every two land parcels (see as two nodes) can be calculated. Energy production cost depends on energy conversation technologies and the technologies selection based on the type of land use. In fact, when the land use (such as land use type, development intensity, planning population etc.) of the parcel is identified the frequently-used energy conversion technology is clear.

3. Stage1: Optimization model

Different land parcel can use different energy conversion technologies, which mean different cost to produce energy commodities. A constrain optimization model can be used to determine the energy produce and transfer structure. The optimization target is minimum total cost, the constraint conditions including demand constrain and energy resource constrain (as Fig 2 illustrated). The variable xi,j means the quantity of energy commodity transfer from node i to j, the variables listed inTable1.

The mathematical model as Eq (1) and the optimization result as Fig1 illustrated.

$$\min S = C \cdot X \tag{1}$$

Subject to $Aeq \cdot X = beq$, $A \cdot X \leq b$ and $X \geq 0$.

Where X is decision variables, instead of the quantity of heat from one land parcel import/export to the others, MW; C is total cost coefficient associated with X; Aeq and A separately instead of secondary energy demand and energy produce capacity constraint matrix; column vector beq and b separately stand for calculate secondary demand and energy produce capacity of every land parcels, MW.

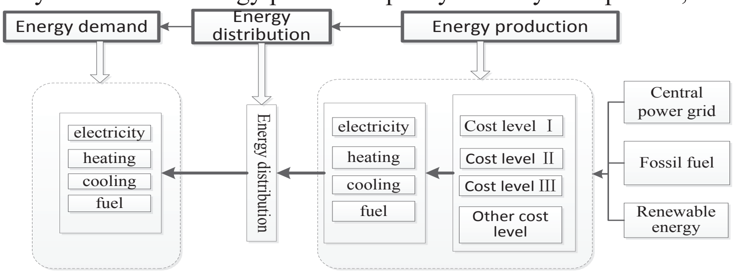

Fig. 2: Three sub-module of community energy system optimizing model

4. Stage2: Goal Programming

From Eq1 we can get the minimum total cost S and xi,j. The constraint matrix and constrain vector are rigid restrictions which means the minimum S and every xi,j can’t be change. At urban detailed planning stage the energy data with high uncertainty, energy demand and energy resource data may be changed at future. In order to analysis the energy utilization in the community we should consider of the data uncertainty. So the above rigid and strict constrain optimization analysis has many limitations. The Goal Programming (GP) with relax constrain matrix can be used to make further analysis base on the above results.

The mathematical model of GP as follows presents equations.

$$\min \mathrm{a} = \sum_{\mathrm{i}=0}^{\mathrm{m}} [\mathrm{w}_{\mathrm{i}}^{-} \quad \mathrm{w}_{\mathrm{i}}^{+}] \begin{bmatrix} \mathrm{d}_{\mathrm{i}}^{-} \\ \mathrm{d}_{\mathrm{i}}^{+} \end{bmatrix} \tag{2}$$

Subject to $\mathrm{S} + d_0^- - d_0^+ = S_0$, $\mathbf{Ax} + \boldsymbol{d}^- - \boldsymbol{d}^+ = \mathbf{b}$, $\mathbf{x} \geq \mathbf{0}$, $\mathbf{b} \geq \mathbf{0}$, $\mathbf{d} \geq \mathbf{0}$, $\mathbf{w} \geq \mathbf{0}$.Where w is the weight associate with deviational variables d.

5. Case study

5.1 General Description

The project is at Tianjin located in cold climate based on the climates classification in China. The area of this project is 1.1square kilometres. Planning area is planned for residential land, residential business, large scale business, hospital, school, office land, urban greenbelt, road and public service facilities land, which is a mix-land use community. We use this community heating system planning as an example to discuss the utilization of two-stage optimization method.

5.2 Energy commodity production and distribution

In this discussion, we use Fossil Energy Consumption Ratio (FECR) as the universal cost. FECR is the fossil energy expend when acquired unit quantity secondary energy commodity. In this paper the secondary energy commodity is hot water. "Fossil Energy Consumption Ratio" (FECR) is calculated by divide the quantity of fossil energy consumed by its thermal energy output. For different heat produce technologies the FECR calculated method and equations are discussed and listed by Zishuo Huang in related material [11].Based on the land use of each land parcel and urban database, the heat demand and reasonable FECR of every land parcel are listed in Table 1.

Table 1. Space coordinates and the heat production FECR in every land parcel

Number	Coordinates		D_i	D_{output}	$FECR_{heat,\ source}$ [a]	Number	Coordinates		D_i	D_{output}	$FECR_{heat,\ source}$ [a]
	x	y					x	y			
1	130	115	1.69	0	0.0378	6	990	485	0.73	2.73	0.0129
2	390	115	1.43	0	0.0378	7	670	475	3.21	7.71	0.0242
3	690	115	2.14	3.64	0.0242	8	510	475	1.42	0	0.037
4	1270	115	1.86	0	0.0242	9	130	475	4.31	0	0.0427
5	1260	151	0.98	3.98	0.0242						

[a] In this case, there is only one heat production FECR to use. But, that doesn't mean that only one can be used in other projects.

According to GIS data, every node's coordinates can be listed after reference point is designated. The pipeline length from j to i (Lij) can be calculated easily from the coordinates.

The total $FECR_t$ from heat production to heat users are listed in Table 2, which is equal to heat production cost plus to heat transportation cost.

5.3 Optimization results

From the use of linprog solver in MATLAB R2010a, the constrained optimization model solved easily. The optimization result listed in Table 2. The FEC of whole community is 0.2212kgce/s which means in order to meet the community heating demand the fossil energy consumption ratio is 0.2122kgce/s.

Table 2. $FECR_t$ and optimization result (kgce/s/MW)

$FECR_t$/ P_{s0}	Local	3	5	6	7
1	0.03780/0	0.02454/0.389	0.0251/0	0.01332/1.732	0.02474/0
2	0.03780/0	0.02438/1.28	0.02494/0	0.01323/0	0.02459/0
4	0.03780/0	0.02455/0	0.02442/1.56	0.01312/0	0.02478/0
8	0.03780/0	0.02459/0	0.02471/0	0.01310/0	0.02436/1.22
9	0.04270/0	0.02475/0	0.02488/0	0.01320/0.454	0.02453/3.406

5.4 Goal Programming result

During the goal programming discussion, we suppose two scenario analyses. Scenario 1 (S1): every land parcels' (1, 2, 4, 8, 9) energy demand at least decrease 10% but less than 30%, the energy suppliers (3, 5, 6, 7) increase energy produce within 30%. Scenario 2 (S2): every land parcels' (1, 2, 4, 8, 9) energy demand at least increase 10% but less than 30%, the energy suppliers (3, 5, 6, 7) reduce energy produce within 30%. The weight of deviation variables listed in Table 3. S1 and S2 results are listed in Table 4. In S1 the total FEC is 0.2144kgce/s. In S2 the total FEC is 0.2399kgce/s. From the goal programming we can discuss the energy system planning result when variables changed within certain scope, which is very useful during urban detailed planning stage.

Based on the results listed in Table 4, the optimization community heating system structure can be descript and the minimum fossil energy consumption ratio is acquirable, which information can help to make an energy municipal planning and give a reasonable energy consumption target.

Table 3. The weight of deviation variables in S1 and S2

	d_1^-	d_1^+	d_2^-	d_2^+	d_3^-	d_3^+	d_4^-	d_4^+	d_5^-	d_5^+	d_6^-	d_6^+	d_7^-	d_7^+	d_8^-	d_8^+	d_9^-	d_9^+	d_0^-	d_0^+
w_1	0.4	0.6	0.4	0.6	0.4	0.6	0.4	0.6	0.4	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0	1
w_2	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	0.7	0.3	0.7	0.3	0.7	0.3	0.7	0	0.5

Table 4. The quantity of heat produced and received in every land parcel during S1 and S2 (MW)

P_{s1}	Local	3	5	6	7	P_{s2}	Local	3	5	6	7
1	1.019	0	0	0.24	0	1	0	0.07	0	1.62	0
2	0	1.331	0	0.249	0	2	0	1.43	0	0	0
4	0	0	2.16	0	0	4	0	0	1.86	0	0
8	0	0	0.2787	0	1.3413	8	0	0	0.1679	0	1.2521
9	0	0	0.4183	1.325	3.0167	9	0	0	0.6821	0.38	3.2479

6. Conclusions

It's necessary to discuss the community heating system structure and set fossil energy consumption target at community energy planning stage [12, 13]. Use the procedure introduced in this paper, more reliable and suitable FECR values have been put forward to regulate energy regulation index. This planning model can not only compare the FEC of different scenarios, but also provide an "ideal system scheme". From goal programming model, planners can give an overall and deep perception on community energy system. What's even more important is that this method can give suggestions and assistance for designers to design a more reasonable community heating system at the construction stage. Though the analysis of the case study is static, dynamic analysis also can be conducted if hourly load data are available. So this paper gives a sketch for community energy system optimization which does not constitute an impeccable handbook.

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Biography

Prof. Hang Yu, received a doctor degree in Science of Human Settlements from Kyushu University in 2001. From 1990 to now as a teacher in Tongji University, PhD Director. Have many research achieverment in Building energy efficiency, Renewable and alternative energy sources, Low carbon technologies and Indoor thermal comfort.